Implementing 3D Geovisualization in Spatial Data Infrastructures: The Pros and Cons of 3D Portrayal Services

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1 INTRODUCTION

Visual representations of geospatial information proved to be valuable means to facilitate thinking, understanding, and knowledge construction about human and physical environments, at geographic scales of measurement (MacEachren and Kraak, 2001). Massive amounts of distributed and heterogeneous geospatial information and geospatial computing functionality are increasingly available as distributed resources that can be accessed through the Internet. This increased availability has created the demand and feasibility to build distributed systems that leverage these resources for visualizing and interacting with geospatial information.

For the implementation of such distributed systems, the application of the architectural concept *service-oriented architecture* (SOA) (e.g., (Krafzig et al., 2004, Hildebrandt et al., 2008)) and standards from the Open Geospatial Consortium (OGC, www.opengeospatial.org) are commonly proposed. The primary potential of the application of the SOA paradigm in the geospatial domain is that it supports the uniform access, exploitation, integration, and reuse of distributed geodata and geospatial functionality. The application of the SOA paradigm for designing geovisualization systems implies the functional decomposition of the geovisualization process into reusable services accessible through a network. The OGC has approved various standards for service interfaces, data models and data encodings in the geospatial domain. For the presentation of information to humans, the OGC proposes *portrayal services*. For 2D portrayal, the *Web Map Service* (WMS) (de la Beaujardiere, 2006) is proposed as an approved standard, whereas for 3D portrayal the *Web 3D Service* (W3DS) (Quadt and Kolbe, 2005) and the *Web Perspective View Service* (WPVS) (Singh, 2001) are proposed as different approaches that are both still in the early stages of the standardization process. The major difference in the current proposals for the 3D portrayal services is the representation that they generate. The W3DS delivers scene graphs that are to be rendered by the client, whereas the WPVS delivers rendered images that are ready for display.

In this paper, we characterize, discuss, and compare the W3DS and WPVS portrayal services as proposed by the OGC with a particular focus on their application to portray complex virtual 3D city models. We discuss the potentials and limitations of the different approaches and the conditions under which they can be applied in an effective and value adding way. With this contribution, we aim at supporting decision makers in choosing portrayal services meeting their requirements for *spatial data infrastructures* (SDI), the present process of standardizing 3D portrayal services and related research.

The remainder of the paper is organized as follows. Section 2 briefly investigates characteristics of virtual 3D city models as exemplary input for the geovisualization process. Section 3 illustrates fundamental possibilities to decompose functionally the geovisualization process in a SOA. Section 4 systematically compares the 3D portrayal services W3DS and WPVS. Finally, Section 5 concludes the paper and outlines current and future work.

2 CHARACTERISTICS OF VIRTUAL 3D CITY MODELS

Virtual 3D city models are digital, georeferenced representations of spatial objects, structures and phenomenons of urban areas, which are increasingly built and leveraged in various application areas such as urban planning, environmental management, and tourism. They represent information models that can be used for 3D presentations, 3D analysis, and 3D simulations. Virtual 3D city models are essential components of SDIs because of their capability to act effectively as integration platforms for georeferenced information. The OGC proposes CityGML (Gröger et al., 2008) as a semantic information model and exchange format for virtual 3D city models. It contains models for digital terrain, buildings, vegetation objects, water bodies, transportation objects, city furniture, land use, and more.

To illustrate the inherent complexity of virtual 3D city models, in the following, we briefy estimate the storage requirements for a hypothetical city model of Berlin in moderate detail consisting of a digital terrain model, aerial images, and fully and individually textured building models. The city of Berlin covers an area of approximately 890 km^2 and encompasses approximately 550.000 buildings. A digital terrain model consisting of an elevation model (sampled at 5m intervals) and aerial images (sampled at 20cm) requires 294 MB for the geometry (uncompressed) and 10.610 MB for the images (including mipmaps, S3 texture compression). A model of all buildings represented at the coarsest geometrical level-of-detail as block buildings and fully textured (one 512 x 512 texture per building) requires 180 MB for the geometry (CityGML, compressed) and 71.500 MB for the textures (including mipmaps, S3TC). In total, the digital terrain model and building models require about 82,6 GB. Including models of additional types (e.g., vegetation, city furniture) and of higher detail (e.g., highly detailed building models) can further increase the storage requirements signifcantly.

3 DECOMPOSITION OF THE GEOVISUALIZATION PIPELINE

3.1 Architectural Framework

In this Section, we present an architectural framework that organizes and relates SOA concepts, geovisualization concepts, and OGC standards in a common conceptual frame of reference in order to allow for a differentiated discussion of the portrayal services in the following Sections. When applying the architectural concept SOA, a distributed system is functionally decomposed into services. By applying the principle of separation of concerns, the services are "cut" in such a manner that they can ideally be assigned to one of a set of given categories. A common set of categories consists of the categories *data*, *functionality*, *process,* and *interaction* (Krafzig et al., 2004, Hildebrandt et al., 2008) each defining a layer in a layered software architecture (Fig. 1).

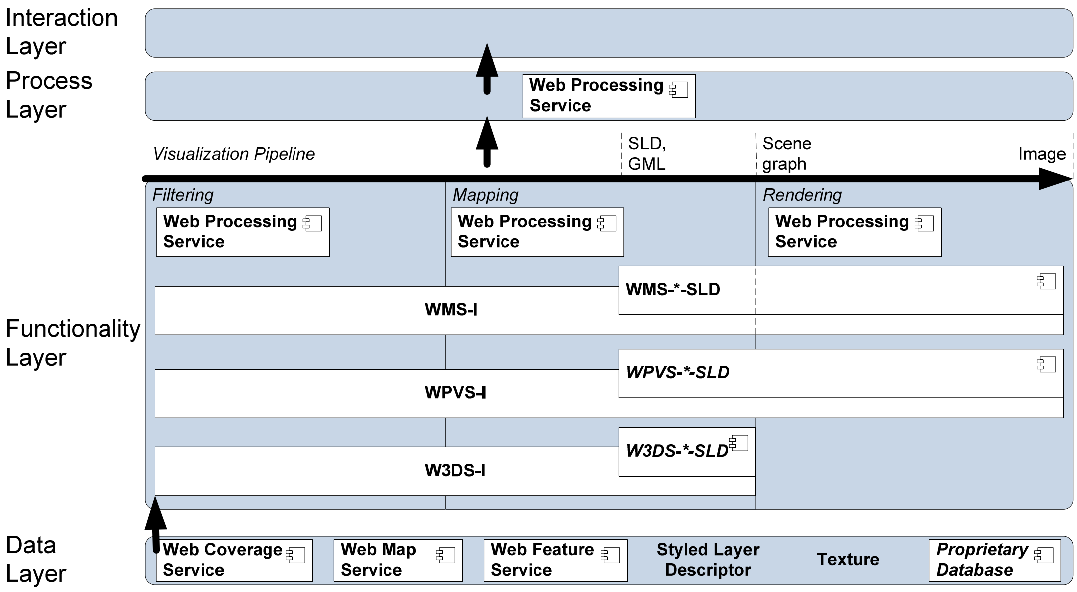

Figure 1: Architectural framework relating SOA concepts, geovisualization concepts, and OGC standard proposals (major data flow indicated by bold arrows).

The visualization pipeline (Haber and McNabb, 1990) is a well-established concept for separating the concerns of the process of generating visual representations from data in three stages. The filtering stage maps raw data to refined data by extracting the data of interest from the raw data and performing preprocessing on it (e.g., data reduction, filtering, or conversion). The mapping stage maps refined data to data representing geometric primitives and their visual attributes. Finally, the rendering stage maps the outcome of the mapping stage to a digital image. The concept of the visualization pipeline can effectively act as a guide on how concerns should be separated when decomposing visualization functionality into services and aid in analyzing existing proposals for portrayal services. In Figure 1, we assign the service proposals by the OGC and other resources that are directly relevant in the context of portrayal to the respective layers and visualization pipeline stages if applicable.

3.2 Portrayal Services

For 2D portrayal, the OGC proposes the WMS as an adopted standard. A WMS is capable of generating map-like 2D visual representations as images. It implements the complete visualization pipeline from the filtering to the rendering stage. A WMS is supposed to integrate closely and transparently the geodata resources that it can process. To a client, it advertises predefined layers of features from its geodata resources and predefined styles for mapping the feature layers to geometrical representations as identifiers. From a client, the WMS accepts as the most relevant input a list of named layers and associated named styles, a bounding box and a viewing specification. The *Styled Layer Descriptor* (SLD) (Lupp, 2007) adopted standard extends the capabilities of a basic WMS by user-defined styling. By passing a SLD to the service, the client specifies what features to portray and how to style them. Furthermore, the concepts of a *component WMS* and an *integrated WMS* are introduced. A component WMS does not closely integrate geodata and can portray features from remote WFS or WCS sources as specifieed by a SLD. On the contrary, an integrated WMS closely integrates geodata like the basic WMS but allows for the selective and user-defined portrayal as specified by a SLD.

For 3D portrayal, the OGC proposes the W3DS and WPVS. The W3DS specification is presently proposed as a discussion paper. In its present proposal, it is responsible for implementing the filtering and mapping stages of the visualization pipeline. Analog to the basic WMS, the W3DS closely and transparently integrates geodata resources and offers a similar interface to clients. As output, it generates a scene graph, which represents a computer graphical description of geospatial data that has to be rendered by the client. The WPVS is the current, internal working revision of the *Web Terrain Server* (WTS) discussion paper (Singh, 2001). Until an updated specification for the WPVS is made publicly available, the terms WPVS and WTS can be used interchangeably. In its present proposal, the WPVS implements the complete visualization pipeline. In accordance with the basic WMS and W3DS, the WPVS closely and transparently integrates geodata resources and offers a similar interface to clients. As output, the WPVS generates rendered images that are ready to be displayed by clients.

3.3 Portrayal Service Capabilites

For portrayal services, at least three basic capabilities can be distinguished that were introduced by the SLD specfcation for WMS. In order to allow for a differentiated analysis and discussion of portrayal services in general, we structure these basic capabilities and make them explicit under the following notions. The capability *integrated* denotes that a portrayal service stores geodata locally and can portray the contained geodata. The capability *component* denotes that a portrayal service can access remote geodata through OGC interfaces and portray such remote geodata. The capability *SLD* denotes that a portrayal service supports selective and user-defined portrayal of all geodata it can access.

As illustrated in Figure 2, the three capabilities can be combined to model four different types of portrayal services. The service types *integrated* (“I”), *integrated-SLD* (“I-SLD”) and *component-SLD* (“C-SLD”) can be characterized analogously to the basic WMS, integrated WMS and component WMS respectively described in Section 3.2. The service type *integrated-component-SLD* (“IC-SLD”) combines all three capabilities. Please note that we do not propose the service types *component* and *SLD*. The former is not useful since generally a portrayal service cannot effectively style geodata with arbitrary, unknown content. The latter is not useful since the portrayal service needs at least one specified source of geodata. A notable difference between *-SLD and I services is that conceptually the former do not implement the filtering stage and the mapping stage only to some extent, whereas the latter implements both stages (Fig. 1). Generally, we regard a SLD document as a visualization specification that is the outcome of separate filtering and mapping stages. When passed to a *-SLD portrayal service, the service retrieves and styles features as specified in the SLD document. For example, a process for the visualization of simulation data might employ specialized, complex filtering and mapping services to preprocess the raw simulation and to generate a SLD that is then passed to a portrayal service. As discussed in Section 4, the set of capabilities a portrayal service supports has significant implications on characteristics such as the applicability, performance, scalability, and implementation complexity of the service. In contrast to 2D portrayal, no SLD specification exists by the OGC that is applicable for 3D portrayal. Thus, there is not yet formally a way to specify the C-SLD, I-SLD and IC-SLD types of the W3DS and WPVS. However, proposals for extending the SLD for 3D portrayal already exist (Haist et al., 2007, Neubauer and Zipf, 2007).

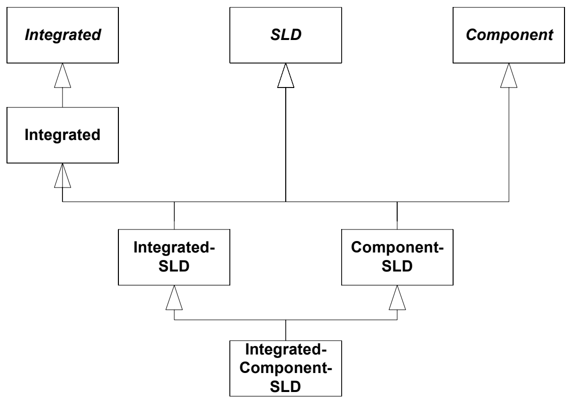

Figure 2: Four portrayal service types derived from three basic portrayal service capabilities.

4 COMPARISON OF 3D PORTRAYAL SERVICES

In this Section, we systematically estimate and compare the 3D portrayal services W3DS and WPVS differentiated by their capabilities as introduced in Section 3.3 along the dimensions visual quality, client-side characteristics, network communication, server-side characteristics, and geodata and content aspects. Figure 3 summarizes the results. In the following, we briefly comment on the results.

Visual quality refers to the potential of a service to produce effective visual representations by utilizing adequate visualization techniques and methods. The WPVS has full control over the rendering stage (+), whereas W3DS-based portrayal is restricted by the limiting capabilities of the rendering client and the scene graph description employed by the W3DS (e.g., VRML) (-). I services have full control over the filtering and mapping stages (+), whereas *-SLD services have no control over these stages and can only portray what is expressible by SLD documents (-). WPVS-based portrayal has the potential to be easily integrated into existing or adapted to changing processes since images can be retrieved via a simple REST interface, web application integration is straightforward and there is no necessity to install specific software (+). W3DS-based portrayal requires installation of specific software on the client. Developing and integrating custom client software may be inevitable if generic client software (e.g., VRML browser plugin) does not support specific requirements (-). *-SLD services offer user-defined styling and thus can be adapted to existing requirements more easily (+) than I services (-). The degree of interaction refers to the potential that the visualization process can be manipulated and reactions to manipulations are displayed with low latency. W3DS-based portrayal allows for ad hoc, low latency manipulations and analysis of the scene graph and camera specification on the client (+). WPVS-based portrayal implies high latency manipulations of the camera specification and no possibilities to manipulate or analyze the scene graph (-). *-SLD services allow for interactive, high latency control of parts of the filtering and mapping stages (+), whereas I services offer very limited, high latency control through named layers and styles (-). Software development complexity for W3DS-based portrayal is rated high since we estimate that for the many applications a specific client has to be developed (-). WPVS-based portrayal requires very little software development effort on the client-side (+). Explicitly creating custom SLD documents by clients of *-SLD services is estimated to demand moderate efforts (o). Software installation effort on the client-side is rated high for W3DS-based portrayal (-) and low for WPVS-based portrayal (+). Required hardware resources are estimated high for W3DS-based portrayal since the client has to store and render the scene graph locally (-) and low for WPVS-based portrayal since the client only has to store and display images (+).

The transmission load from service to client is rated very high for W3DS-based portrayal since considerable portions of the original model have to be transferred (-). This poses challenges especially for the portrayal of complex 3D city models (see Section 2). For WPVS-based portrayal, the transmission load from service to client primarily depends on the display resolution and is agnostic to the model complexity (+) making it suitable especially for clients on mobile devices. I services have the potential to produce very little transmission load from other sources to the service because of its closely coupled sources (+). C-SLD services have to retrieve all the geodata they process from remote sources (-).

On the server-side, concerning software development complexity a W3DS is potentially less complex (+) than a WPVS (-). A WPVS has to implement the complete rendering stage that can be highly complex if the results are required to be of high quality. In contrast, though a W3DS does not implement the rendering stage, it outputs a complex data structure. I services do not have a public interface for importing external geodata, however, geodata needs to be preprocessed when imported internally (o). *-SLD services are required to interpret complex SLD documents (-). I-SLD services are required to have internally stored geodata accessible by SLD (-). Required hardware resources are estimated moderate for the W3DS since it does not implement the complex rendering stage (o) like the WPVS (-). I services must be capable of storing massive amounts of geodata (-). I-SLD services are required to execute complex SLD documents and, conceptually, may have two parallel data structures that are optimized for rendering and SLD access respectively (-). C-SLD services do not have to store model data (o).

Criterion / Portrayal Service	W3DS–I	W3DS–I–SLD	W3DS–C–SLD	W3DS–IC–SLD	WPVS–I	WPVS–I–SLD	WPVS–C–SLD	WPVS–IC–SLD	WPVS+–I–SLD
Visual quality	o	–	–	–	+	o	o	o	+
Client–side characteristics									
Possible degree of interaction	o	++	+	+	– –	o	–	–	+
Process integration complexity	– –	o	o	o	o	++	++	++	o
Software development effort	–	– –	– –	– –	++	+	+	+	o
Software installation required	–	–	–	–	+	+	+	+	o
Required hardware ressources	–	–	–	–	+	+	+	+	o
Administration and maintainance effort	–	–	–	–	+	+	+	+	o
Network communication									
Transmission load service to client	– –	– –	– –	– –	++	++	++	++	+
Transmission load to service	++	++	– –	– –	++	++	– –	– –	++
Server–side characteristics									
Software development effort	o	–	–	–	–	– –	– –	– –	– –
Required hardware ressources	–	– –	o	– –	–	– –	–	– –	– –
Administration and maintainance effort	–	–	o	–	– –	– –	–	– –	– –
Geodata and content aspects									
Geodata integration	–	–	++	++	– –	– –	+	+	o
Geodata udpating	–	– –	++	o	–	– –	++	o	– –
Licensing and privacy	o	o	–	–	++	++	+	+	+

Figure 3: Comparison of 3D portrayal services W3DS and WPVS.

Geodata integration potential is rated high for W3DS-based portrayal since scene graphs can be easily combined (+), whereas, generally, images from a WPVS cannot be integrated (-). I services offer no (-) and *-SLD services high integration potential(+). Geodata updating complexity is estimated high for I services since this type of service is supposed to be most effective if imported geodata is stored in optimized data structures (-). Additionally, I-SLD services need to make internally stored geodata accessible by SLD (-). C-SLD services are not affected by geodata updating(+). Licensing and privacy concerns are estimated to be best protected by WPVS-based portrayal because only images are transferred to clients(+), whereas a W3DS transfers large portions of the model(-). C-SLD services may be vulnerable since geodata is transferred over the network (-). I-SLD and I services are not affected by licensing and privacy concerns (+).

5 SUMMARY AND CONCLUSION

In this paper, we illustrated the inherent complexity of virtual 3D city models as input to 3D portrayal services, presented fundamental possibilites to decompose the geovisualization process and presented a comparison of the W3DS and WPVS portrayal services pointing out their respective strengths and weaknesses.

The discussion of the 3D portrayal services revealed several issues that should be addressed in the future. In many respects, the capabilities of the W3DS and WPVS are oppositional. For example, neither service is ideal for the service-based visualization of complex models that requires high quality outputs and client-side navigation capabilities. For this reason, we presently research an extension to the WPVS named "WPVS+" that strikes a balance between W3DS and WPVS by offering additional capabilities such as providing additional information per pixel besides color that the client exploits intelligently. Our preliminary estimation on the characteristics of the WPVS+ is reflected in Figure 3. Further areas for future work include the integration of multi representation and level-of-detail concepts into the W3DS to make W3DS-based portrayal more scalable, elaborating and standardizing SLD for 3D portrayal, and researching the feasibility of a new portrayal service variation that accesses remote geodata, optimizes it, and stores it locally for increased performance.

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